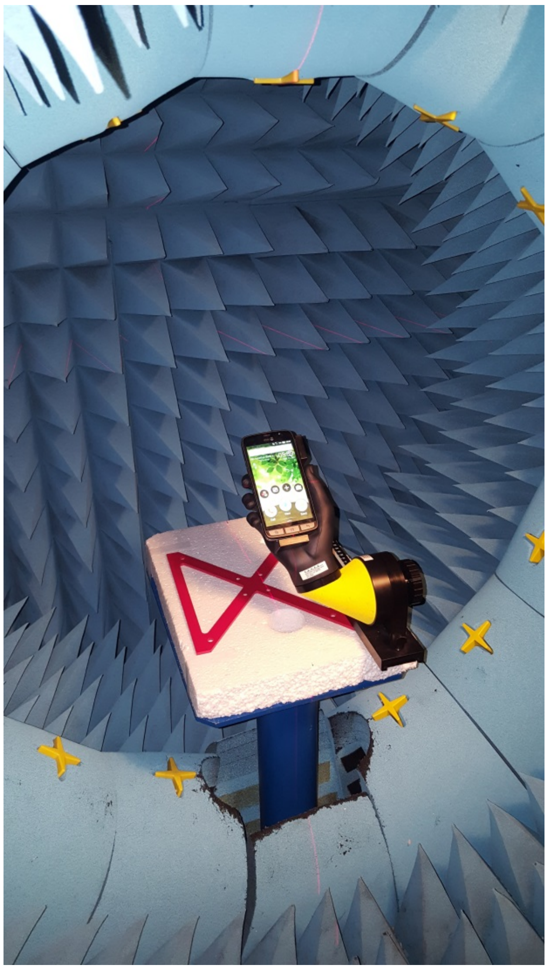
Mobile Phone Antenna Performance 2016

Pedersen, Gert F.

Publication date:
2016

Citation for published version (APA):
Pedersen, G. F. (2016). *Mobile Phone Antenna Performance 2016*. Nordic Council of Ministers.

Mobile Phone Antenna Performance 2016




Version 4.0, September 2016

Gert Frølund Pedersen
Professor, PhD
Aalborg University

norden
Nordic Council of Ministers

Introduction

This study investigates the antenna performance of a number of mobile phones widely used in the Nordic Countries. The study is supported by the Nordic Council of Ministers.

The antenna performance of the phones is vital for the phones ability to ensure radio coverage in low signal situations. The study is based on the mobile systems in the Nordic mobile networks and on both speech and data services. The selected phone models are among the most popular new phones at the time of this study.

In order to ensure a connection between the mobile phone and the base station, a link is needed both from the phone to the base station (the phone is transmitting and the base station is receiving) and from the base station to the mobile phone (the base station is transmitting and the mobile phone is receiving). The weakest link determines the quality of the connection, and thereby also the coverage. For voice service the weakest link is typically the link from the mobile phone to the base station, called the uplink by mobile network operators. For data services, the weakest link is the downlink according to information received from the Danish Energy Agency. Therefore, the current study focuses on the *transmitter* performance for voice service and the *receiver* performance for data mode, as these are the crucial links in **weak radio signal conditions**.

The transmitter and receiver performance depends strongly on the antenna in the phone and on the way the user is holding the phone to the head during a call or in the hand during browsing mode [Pel09]. If the phone is not hand held but used in e.g. a hands-free installation or connected to a headset, the phone itself may be placed free of any close-by objects. In this case the ability to collect a radio signal is generally significantly better.

The test is often referred to as the antenna test, even though the test includes more than the antenna. The transmitter and the receiver electronics are also included in the tests, but since these parts must fulfil the requirements in the technology standards, this performance typically has a rather low degree of variations between different models. The main difference in performance is due to differences in antenna design, in combination with how the user is handling the phone.

The study is a follow-up on similar studies conducted in 2012 and 2013 on phone models common in the market at that time [Ped12, Ped13]. The aim of the earlier study was to establish the field strength calculations for mobile voice service and to determine the minimum field strength needed to ensure coverage, see appendix II [Erst12]. The predicted field strength values for all mobile networks using the mobile standards GSM and UMTS for the 900, 1800 and 2100 MHz frequency bands everywhere in Denmark were then compared to the minimum values and a combined coverage map was produced by the Danish authorities [Erst12].

The present study investigates mobile phones and tablets ability to ensure a connection in a weak radio signal condition. Therefore measures of the phones ability to transmit for voice service and receive for data services are measured. Further, the test for voice services in the present study includes test using the phone on both sides of the head.

Also a small number of tablets are included in the present test.

Test Procedure

Test of communication performance for mobile terminals are based on tests of the terminals ability to transmit *to* the base station and receive *from* the base station. The mobile terminal can adjust its power according to the needs and to test the terminals ability to connect in a weak radio signal situation the terminal is requested to transmit with the highest transmit power. The maximum transmit power depend on the mobile system, band of operation and on the power class of the mobile terminal. Generally the terminals can transmit with 33 dBm for GSM900, 24 dBm for UMTS900 and UMTS2100 and 30 dBm for GSM1800. The higher transmit power for the GSM system is caused by the fact that the terminal for GSM only transmit in bursts of approximately 1/8 of the time whereas the UMTS system transmit continually.

The tests conducted in the study are based on the agreed standard test procedures for mobile phones, created by the Cellular Telecommunications Industry Association (CTIA) [CTIA15] with a few exceptions. These exceptions are:

For voice service:
In the case where more than one antenna can transmit (named BAS) the measurements are performed in the same way as for phones with no antenna selection. The antenna selection (BAS) is a feature in some phones whereby the phone automatically selects which antenna to use at any time. This way the phone selects, by itself, the best antenna for the test situation. The deviation from the standard is made, since a special modified test phone is required for the standardised test, but such a modified phone is not commercially available.

For data service:
Each antenna (of typically two) for a dedicated system and frequency band must be measured individually by disabling the automatic (BAS) antenna switching system used in normal operation. The measurements conducted in this study allow the phone to make the antenna switching as it see fit. The deviation from the standard is made, since a special modified test phone is required for the standardised test, but such a modified phone is not commercially available.

To limit the number of tests on each phone only the frequency bands used in the Nordic countries (and in Europe) are measured and only the centre channel as a representative of the band. Further, the following situations are studied
For voice service:

1. Phone next to the phantom head, held by a right phantom hand next to the right hand side of the head, referred to as BHHR.
2. Phone next to the phantom head, held by a left phantom hand next to the left hand side of the head, referred to as BHHL.

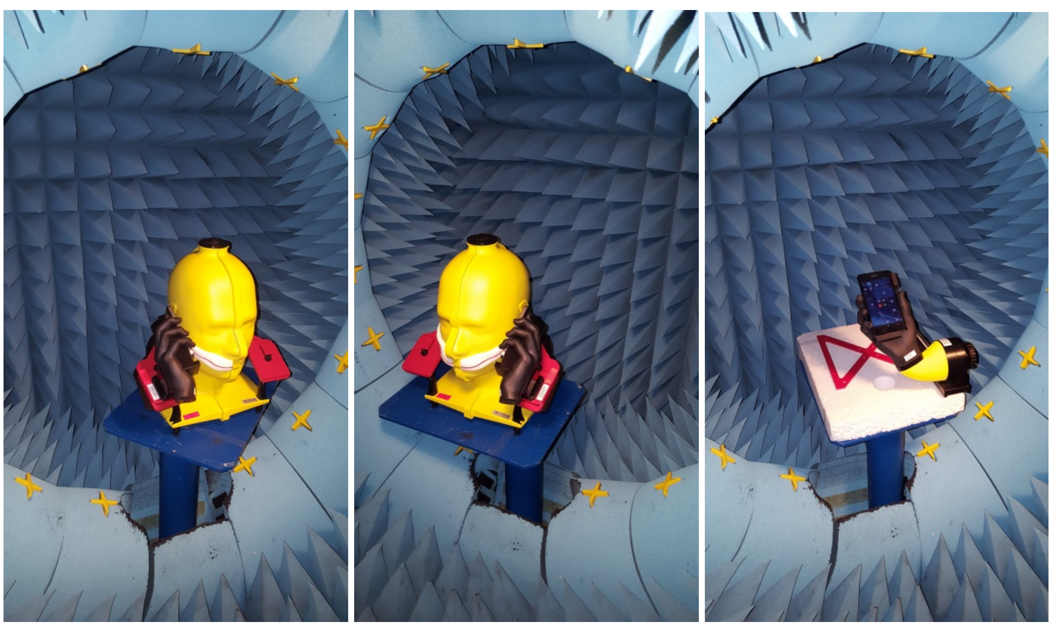
For phones in data services:
The phone is held with the right phantom hand in browsing stance.

For tablets:
For the first test, the performance is measured in "free space", i.e. no phantom head or hand is present. This corresponds to how the performance is measured in the standard specifications. Further a test using 2 standardised hands holding the tablet in portrait position is conducted. This test is not standardised but since holding the tablet using your hands while downloding data could be expected to be a common user behavior (e.g. when browsing the internet, or watching a video), this test is believed to be relevant and is therefore included in the results.

The receiver performance is evaluated in terms of the so-called Total Isotropic Sensitivity (TIS) for each frequency band. The lower the value of the TIS, the smaller a signal the phone requires for operation, and the better the phone is to receive in weak signal areas. Note that TIS is a negative number and -97 dBm is a better performance compared to e.g. -90 dBm.

For the transmitter performance, the evaluation is in terms of the so-called Total Radiated Power (TRP). The higher the TRP the stronger the signal at the base station and the better the connection.

The worst and best performing phones were also measured in free space, i.e. with no phantom hand or head present. By comparing the results obtained with and without the phantom head and hand the user's influence can be measured. The difference between phantom present and free space is often called the body loss.



Setup for voice and data services including the specified phantom. Photo to the left; voice service at the right hand side, named BHHR. Centre photo; voice service at the left hand side of the head, named BHHL. Photo to the right; data service. All phantoms are as specified in the CTIA test plan [CTIA15] and made by Speag AG.

For voice service the performances of the phones are ranked according to the TRP values for the GSM 900 system. For voice coverage, the 900 MHz frequency band is the most important, as it gives the best coverage and has the largest penetration in the Nordic countries. A change in TRP of approximately 2 dB can be taken as a significant difference in coverage.

Mobile phones tested

The phone models tested are listed below. The list of models common in the Nordic countries was provided by the Danish Energy Agency.

Device	**Phone Model**
1	Apple iPhone 6
2	Apple iPhone 6S
3	Apple iPhone 6S Plus
4	Apple iPhone SE
5	Samsung Galaxy S7 Edge
6	Samsung Galaxy S7
7	Samsung Galaxy S6 Edge+
8	Samsung Galaxy S5 Mini
9	Samsung Galaxy J1
10	Sony Xperia Z3 Compact
11	Sony Xperia Z5
12	Sony Xperia Z5 Compact
13	LG G5
14	Microsoft Lumia 640
15	Microsoft Lumia 650
16	Microsoft Lumia 950
17	Nexus 6P
18	Nexus 5X
19	Huawei P9
20	Huawei Honor 7
21	Huawei Y360
22	Xiaomi Mi5
23	HTC 10
24	HTC Desire 626
25	Doro Liberto 825
26	Doro PhoneEasy 530X

Table 1. *List of all the phones tested. The phones are tested in all the Nordic frequency bands and systems each phone supports. The list is provided by the Danish Energy Agency.*

Tablets tested

The tablet models tested are listed below. The list of some tablets used in the Nordic countries was provided by the Danish Energy Agency. Two tablet models were not available (NA) in a version with mobile connect and are not included in the test.

Device	**Tablet Model**
NA	Nexus 9
I	iPad Mini 4
II	iPad Air 2
NA	Microsoft Surface Pro 4
III	Samsung Galaxy Tab S2 9.7
IV	Sony Xperia Z4 Tablet

Table 2. *List of the tablets considered. The four tablets tested are numbered. The list is provided by the Danish Energy Agency.*

Results for mobile phones

All the values of measured receiver sensitivities (TIS) and transmit powers (TRP) are listed in the tables below. The values are averages over all directions and both polarisations, as defined for the so-called Total Isotropic Sensitivity (TIS) for receivers and the Total Radiated Power (TRP) for the transmitters, as defined in, e.g., the CTIA test plan [CTIA15]. The values are in logarithmic scale, as customary for these measurements, and given in *dBm* values (dB above *1 mW*). The smaller the value for the TIS, i.e. the more negative the number, the smaller the signal required for a satisfying connection, and therefore the better the phone. Likewise, the higher the value of the TRP the stronger the signal at the base station and the better. For data services TIS is measured at a bandwidth of 10 MHz for the LTE800 and LTE1800 and 20 MHz bandwidth for LTE2600 as specified in the CTIA standard.

The phones are sorted according to the ability to transmit in the GSM 900 frequency band since it is expected to be the most important system and band for voice coverage in the Nordic countries.

Voice service Right hand (BHHR). TRP values, [dBm]					
Ranking	**Phone model**	**GSM900**	**UMTS900**	**GSM1800**	**UMTS2100**
1	HTC Desire 626	22,5	11,4	20,1	12,8
2	Samsung Galaxy S5 mini	20,7	10,6	20,6	9,8
3	Samsung Galaxy J1	20,4	9,4	16,5	8,7
4	Microsoft Lumia 640	20,3	11,5	20,5	13,5
5	DORO PhoneEasy 530X	20,1	11,1	18,8	11,1
6	Nexus 5X	19,8	11,3	13,1	7,6
7	Sony Xperia Z3 Compact	19,8	11,3	18,7	10,7
8	Sony Xperia Z5	19,4	10,8	17,8	13,4
9	Samsung Galaxy S7 Edge	19,4	10,6	20,4	15,5
10	Microsoft Lumia 650	19,3	10,9	13,8	11,7
11	DORO Liberto 825	19,1	10,1	20,5	12,1
12	Apple iPhone 6S plus	18,7	10,3	13,2	2,4
13	Nexus 6P	18,7	9,1	19,7	9,8
14	Xiaomi Mi5	18,6	9,9	17,5	9,7
15	LG G5	18,4	10,5	8,1	2,4
16	Apple iPhone 6	18,1	8,4	15,1	6,5
17	Samsung Galaxy S7	18,0	10,0	19,9	13,7
18	Huawei Y360	17,4	8,6	20,2	12,8
19	Sony Xperia Z5 compact	17,1	9,5	21,4	14,9
20	Samsung Galaxy S6 Edge+	16,7	5,7	20,1	10,1
21	Huawei Honor 7	16,4	7,9	19,6	13,0
22	Apple iPhone 6S	15,1	8,5	14,2	4,7
23	Apple iPhone SE	14,7	7,4	4,1	-3,0
24	HTC 10	14,0	6,6	16,8	11,1
25	Microsoft Lumia 950	12,7	6,0	15,5	7,4
26	Huawei P9	8,3	0,3	18,4	13,0

Table 3. *Measured* right hand *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 26) according to GSM900 performance, as this is the most important for coverage. Measurements according to the CTIA specifications for talk mode in right hand, labelled as BHHR [CTIA15].*

Voice service Left hand (BHHL). TRP values, [dBm]					
Ranking	**Phone model**	**GSM900**	**UMTS900**	**GSM1800**	**UMTS2100**
1	DORO PhoneEasy 530X	21,8	12,6	20,4	12,7
2	Microsoft Lumia 640	21,6	12,3	23,0	15,3
3	Microsoft Lumia 650	21,1	11,8	19,4	11,8
4	Sony Xperia Z3 Compact	21,0	12,2	18,2	12,1
5	Xiaomi Mi5	20,0	11,5	21,6	14,0
6	HTC Desire 626	19,8	9,2	17,7	11,1
7	Samsung Galaxy S7 Edge	19,6	9,0	20,3	14,8
8	Samsung Galaxy J1	19,3	9,2	20,1	11,5
9	Sony Xperia Z5 compact	19,3	10,8	19,4	12,8
10	Huawei Y360	19,2	10,2	19,4	11,8
11	Samsung Galaxy S5 mini	18,7	8,3	21,5	11,1
12	Sony Xperia Z5	18,3	9,4	20,6	14,7
13	HTC 10	18,2	5,6	17,4	7,0
14	Samsung Galaxy S6 Edge+	18,1	10,9	18,0	14,3
15	DORO Liberto 825	18,0	9,6	18,5	10,6
16	Nexus 6P	17,2	8,3	17,3	8,8
17	Huawei Honor 7	16,0	7,6	20,5	12,7
18	Samsung Galaxy S7	15,5	11,2	19,0	15,6
19	Microsoft Lumia 950	15,3	8,8	19,5	12,9
20	Huawei P9	15,0	8,2	19,0	11,6
21	Nexus 5X	14,5	6,8	20,8	13,1
22	LG G5	12,2	2,5	17,9	6,0
23	Apple iPhone SE	12,1	3,3	18,1	3,6
24	Apple iPhone 6	10,1	7,4	18,0	8,4
25	Apple iPhone 6S	8,7	-0,6	17,9	10,4
26	Apple iPhone 6S plus	6,5	-2,3	18,6	7,5

Table 4. *Measured* left hand *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 26) according to GSM900 performance, as this is the most important for coverage. Measurements according to the CTIA specifications for talk mode in left hand, labelled as BHHL [CTIA15].*

Data service. TIS values, [dBm]						
Ranking	**Phone model**	**LTE800**	**LTE1800**	**LTE2600**	**UMTS900**	**UMTS2100**
1	Microsoft Lumia 640	-93,1	-93,8	-89,8	-106,7	-106,0
2	Samsung Galaxy S6 Edge+	-92,8	-93,0	-88,7	-100,1	-104,8
3	Samsung Galaxy S7 Edge	-92,2	-94,8	-87,2	-103,3	-103,6
4	Samsung Galaxy S7	-91,9	-94,1	-89,9	-101,9	-105,9
5	Microsoft Lumia 650	-91,4	-90,7	-89,8	-106,6	-103,7
6	Samsung Galaxy S5 mini	-90,3	-93,6	-92,5	-101,2	-103,8
7	Nexus 5X	-90,2	-92,5	-87,0	-104,0	-107,1
8	Sony Xperia Z5 compact	-89,9	-93,2	-91,1	-104,3	-106,3
9	Huawei P9	-89,7	-91,0	-89,6	-105,7	-103,6
10	Microsoft Lumia 950	-89,6	-91,1	-85,1	-98,7	-99,0
11	Apple iPhone SE	-89,5	Discon-Nect	-85,8	-104,2	-100,5
12	Sony Xperia Z5	-89,4	-92,0	-88,4	-105,6	-103,5
13	Apple iPhone 6	-89,1	-90,4	-88,6	-104,7	-104,6
14	Apple iPhone 6S	-88,8	-91,4	-89,5	-104,6	-104,5
15	LG G5	-88,4	-88,1	-88,7	-103,7	-99,3
16	Sony Xperia Z3 Compact	-88,3	-91,9	-86,2	-102,4	-103,1
17	Apple iPhone 6S plus	-88,1	-92,7	-89,3	-105,0	-103,4
18	Huawei Honor 7	-88,1	-93,0	-86,7	-101,1	-105,3
19	HTC Desire 626	-85,8	-93,1	-87,7	-106,0	-108,2
20	HTC 10	-84,9	-89,6	-82,5	-98,7	-103,0
21	Nexus 6P	-84,7	-94,7	-85,3	-106,2	-106,4
22	DORO Liberto 825	-84,6	-89,7	-88,8	-102,7	-100,7
23	Xiaomi Mi5	NA	-92,2	-86,9	-101,3	-104,1
	Samsung Galaxy J1	NA	NA	NA	-104,3	-100,4
	Huawei Y360	NA	NA	NA	-102,2	-103,8
	DORO PhoneEasy 530X	NA	NA	NA	-107,1	-102,5

Table 5. *Measured* data service *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 23) according to LTE800 performance. A few phones do not support all bands or systems (listed as NA). Measurements according to the CTIA specifications for data mode in right hand [CTIA15].*

Results for tablets

Tablets are measured in free space according to the CTIA standard [CTIA15]. The value measured is the TIS, as the weakest link for data services is the downlink.

Phantom hands for tablet tests are in fact available [http://www.speag.com/] so data measurements of tablet with hands are provided as informative data. This case is not specified by the CTIA standard which, as of yet, is only testing without hands.

Tablet data service Free space. TIS values, [dBm]					
Tablet model	**LTE800**	**LTE1800**	**LTE2600**	**UMTS900**	**UMTS2100**
Sony Experia Z4 tablet	-97,4	-96,6	-91,9	-110,1	-109,9
Apple iPad Air 2	-97,3	-98,4	-92,9	-111,0	-110,2
Samsung Galaxy Tab S2	-95,8	-96,1	-93,1	-	-
Apple iPad mini 4	-97,4	-97,8	-94,5	-111,4	-111,5

Table 6. *Measured performance of the tablets in free space as specified by CTIA [CTIA15]*

Tablet data service Two hands. TIS values, [dBm]					
Tablet model	**LTE800**	**LTE1800**	**LTE2600**	**UMTS900**	**UMTS2100**
Sony Experia Z4 tablet	-92,2	-91,5	-87,0	-104,9	-104,6
Apple iPad Air 2	-96,8	-98,2	-92,5	-110,4	-109,8
Samsung Galaxy Tab S2	-95,1	-95,7	-92,1	-	-
Apple iPad mini 4	-96,8	-97,5	-94,1	-110,6	-110,8

Table 7. *Measured performance of the tablets in the so-called "two-hand portrait" operation for comparison.*

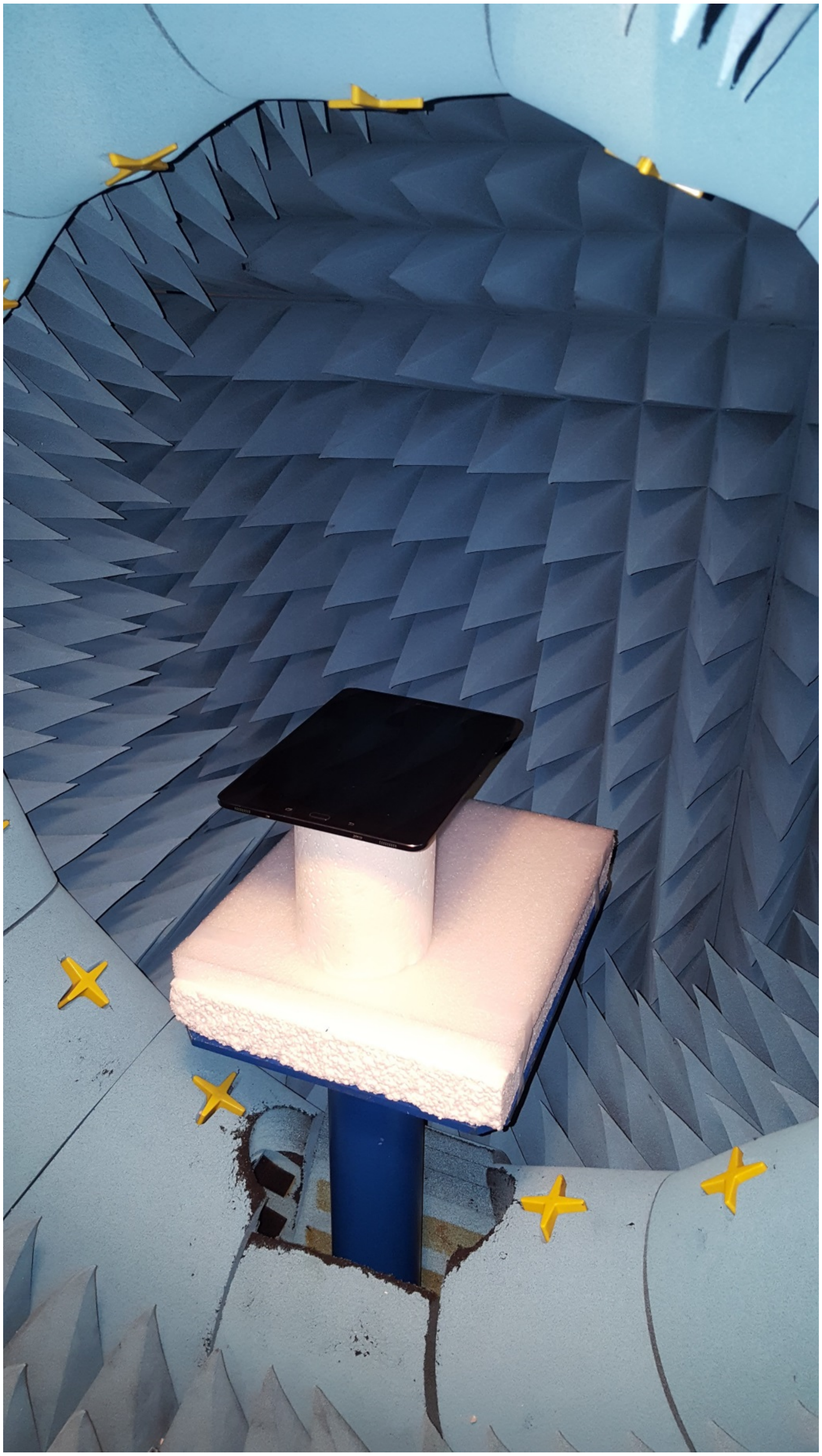


Photo of the setup for measuring tablets according to the CTIA standard. Measurements are performed in free space according to the CTIA standard [CTIA15]

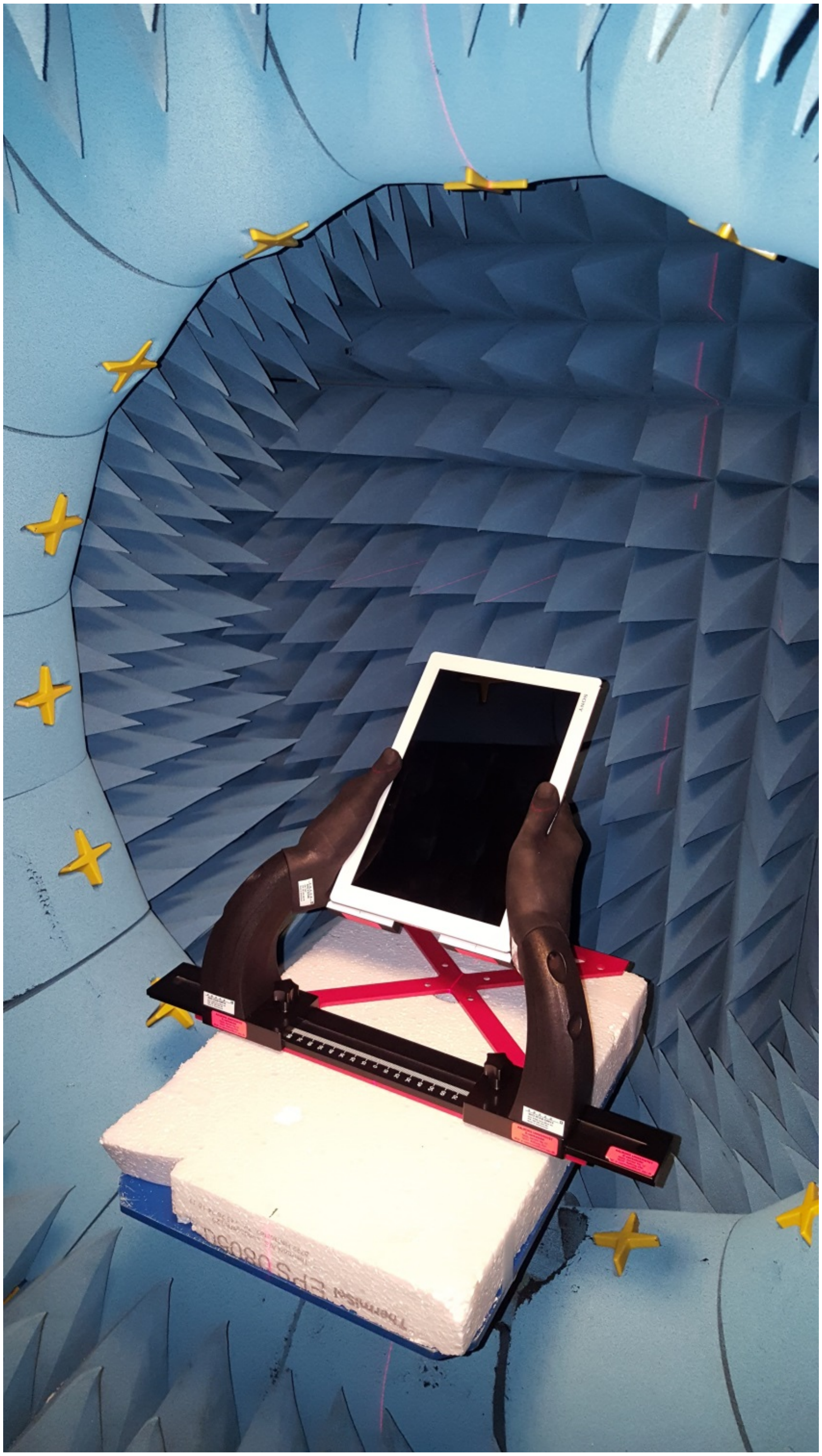


Photo of setup for measuring tablets with two-hand phantoms. As this test is not standardised by CTIA as of now the results are provided as informative data

Free space Reference

The worst performing phones and best performing phones were additionally measured without the phantom hand or head in order to disclose the influence of the human body. The worst performing phones for GSM900 are the "iPhone 6S+" and Huawei P9. The best performing phones for GSM900 are the Doro Phone Easy 530x and the HTC Desire 626. The results are shown in the table below.

Free space vs Voice service for GSM900 phones. TRP [dBm]			
Model	**Free space**	**BHHR**	**BHHL**
iPhone S6+	26,9	18,7	6,5
Huawei P9	27,0	8,3	15,0
Doro Phone Easy 530x	28,4	20,1	21,8
HTC Desire 626	30,9	22,5	19,8

Table 8. *Free space TRP performance of the best and the worst performing phones for voice service in GSM900 (low frequency band). Free space is a measurement of the phone without the phantom head and hand included. Comparing free space to the measurements including the phantom, the head-hand influence can be seen.*

The free space performance results for voice service in GSM900, see Table 8, indicates that the phones perform very well if not used next to the human head and hand. Free space is the situation when used in, e.g., a hands-free installation. The performance of the worst performing phones is actually very good in free space. For the worst performing phones the performance is only very bad in one side of the head.
The difference between free space and the hand-head results for the worst preforming phones are some 20 dB at the GSM900 band. For the best phone the difference is only about 8 dB. A 20 dB reduced TRP performance is equivalent to a reduction of the received power at the base station of 100 times or, in other words, the phone has to transmit with 100 times as much power to obtain the same power level at the base station.

For data services using the highest frequency band, a similar measurement has been performed (LTE 2600 MHz) to investigate the influence of the phantom hand. The two best and worst performing phones have been investigated. See table 9.
The variation between the phones at the highest frequency band is generally not as large as at the lower frequency bands. Further the influence from the hand is also moderate as can be seen by the variation being less than about 5 dB and typically only about 2 dB.

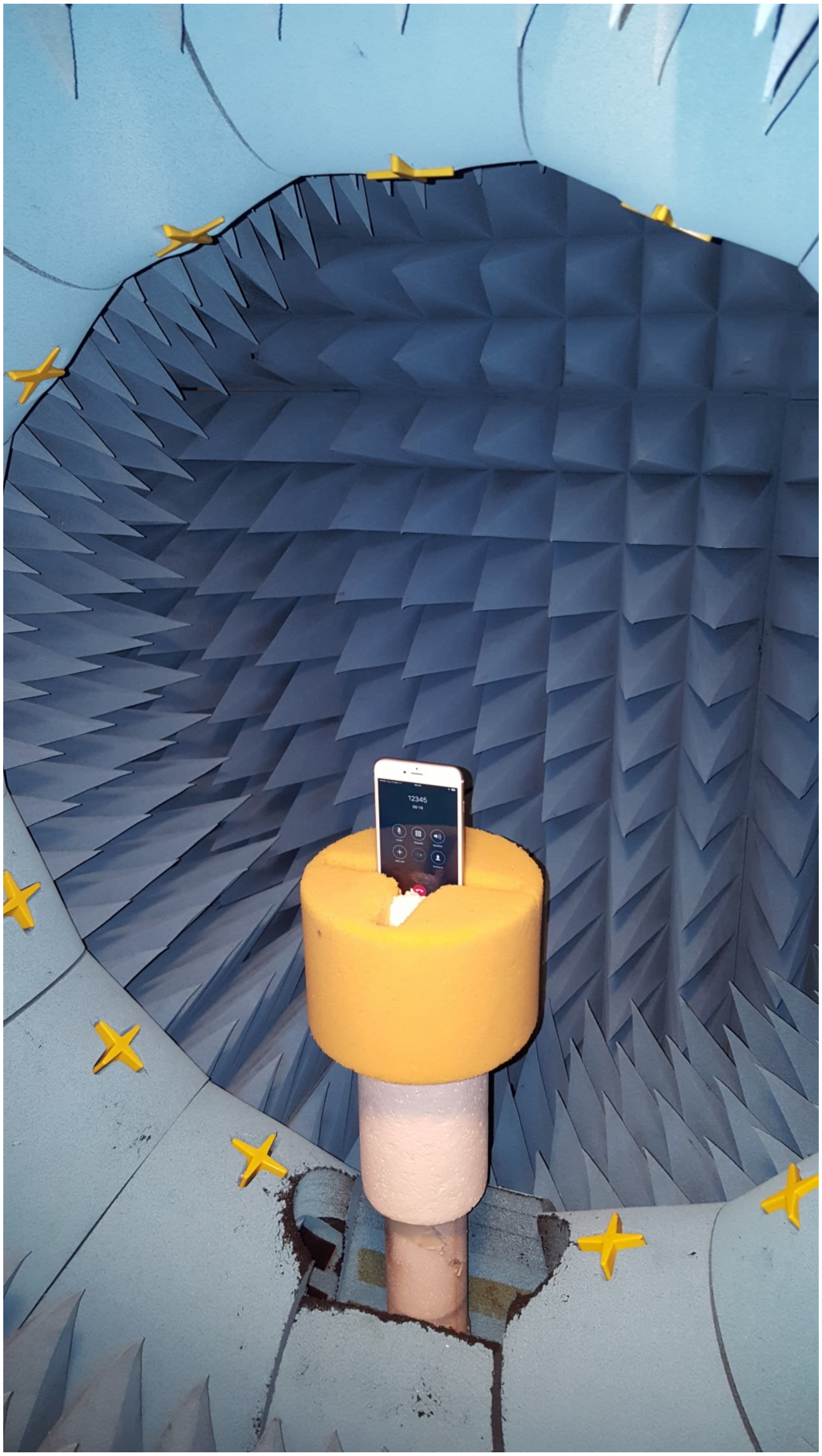


Photo of the setup for measuring phones in free-space according to the CTIA standard [CTIA15]. Measurements are performed in free space as a reference to the phantom measurements to find the bodyloss and check the phones basic performance.

Free space vs data service for LTE2600 phones. TIS [dBm]		
Model	**Free space**	**In Phantom hand**
Samsung S5 mini	-94,9	-92,5
Sony Z5 compact	-92,5	-91,1
Microsoft Lumia 950	-90,5	-85,1
HTC 10	-84,5	-82,5

Table 9. *Free space TIS performance of the best and the worst performing phones for LTE2600 (highest frequency band). Free space is a measurement of the phone without the phantom hand included. Comparing free space to the measurements including the phantom, the hand influence can be seen.*

TIS vs TRP measurements

As mentioned the terminals ability to communicate require that both the link *to* and *from* the base station has an adequate quality. In the previous reports [Ped12, Ped13] the focus was on the link *to* the terminal and the receiver quality in terms of TIS was measured.
The reason for focusing on the TIS was twofold. Firstly to obtain the minimum signal strength for communication which was requested to track the country wide mobile coverage development. Secondarily to list the communication performance of phones and the Danish mobile operators ensured that their mobile networks was in link-balance i.e. up and down link was equally strong. The information from the Nordic mobile operators is that the uplink is the weak link for voice service. And the present report therefore focus on the transmit performance in terms of TRP for voice service.

The influence from the person on the up and down link is rather similar but with some variation due to load-pull of the power amplifier and due to self-interference etc. To exemplify the TIS and TRP performance difference and to allow for comparison with previous results both TRP and TIS measurements are performed for the BHHR case.

The TIS results are listed in table 10. The results are sorted according to the best GSM900 TIS values. As can be seen the order of the phones is not exactly the same when sorted by TIS and TRP but rather similar for the best and worst phones (compere table 3 and table 10). The variations are generally larger for the TRP values than the TIS values but if a few extreme values are omitted the variation is rather similar.

Voice service Right hand (BHHR). TIS values, [dBm]					
Ranking	Phone model	GSM900	UMTS900	GSM1800	UMTS2100
1	Nexus 6P	-99,6	-100,8	-103,0	-102,9
2	HTC Desire 626	-99,5	-102,6	-100,9	-104,7
3	Samsung Galaxy S7 Edge	-98,8	-101,0	-101,1	-103,9
4	DORO PhoneEasy 530X	-98,5	-100,9	-97,9	-101,7
5	Microsoft Lumia 640	-98,5	-103,2	-102,3	-104,8
6	Samsung Galaxy S7	-98,3	-99,8	-100,6	-105,0
7	Microsoft Lumia 650	-97,9	-103,1	-95,6	-102,0
8	Sony Xperia Z5	-97,9	-100,2	-100,6	-102,4
9	Samsung Galaxy S5 mini	-97,8	-97,7	-101,3	-101,7
10	Samsung Galaxy S6 Edge+	-97,8	-97,5	-101,4	-104,0
11	Sony Xperia Z5 compact	-96,8	-100,1	-102,2	-104,0
12	Microsoft Lumia 950	-96,8	-99,5	-99,3	-99,0
13	Xiaomi Mi5	-96,6	-97,4	-100,7	-101,0
14	LG G5	-96,4	-99,7	-96,5	-94,7
15	Nexus 5X	-96,3	-99,4	-99,8	-103,6
16	Sony Xperia Z3 Compact	-95,9	-97,4	-100,3	-100,6
17	Huawei Y360	-95,8	-96,9	-101,7	-102,3
18	DORO Liberto 825	-95,4	-99,2	-99,0	-98,8
19	Huawei Honor 7	-95,3	-97,5	-99,1	-104,0
20	Samsung Galaxy J1	-95,3	-98,6	-98,5	-97,4
21	Apple iPhone SE	-95,3	-99,9	-90,7	-98,9
22	Apple iPhone 6S plus	-95,2	-100,8	-93,1	-97,3
23	HTC 10	-94,3	-94,3	-97,6	-99,3
24	Apple iPhone 6	-94,1	-100,5	-96,7	-102,9
25	Apple iPhone 6S	-93,2	-100,4	-95,7	-101,6
26	Huawei P9	-84,4	-100,4	-96,8	-101,2

Table 10. *Measured* right hand *TIS performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 26) according to GSM900 TIS performance, as this is the most important band for coverage. Measurements according to the CTIA specifications for talk mode in right hand, labelled as BHHR [CTIA15].*

Discussion

The results clearly show that the performance of the different models vary considerably. Most variation is seen for the case of voice service with less variation in the case of data services. The variation among the phones for voice service is between 6 dB and 18 dB across all frequency bands, systems and left or right hand uses. In nearly all cases the variation is 10 dB or higher.

The performance variation between left hand and right hand usage is for several phones very large. This show that for some phones the antenna design does not take body loss in different usage positions into account. A well designed antenna solution has a low body loss in both right and left hand usages.

The body-loss, which is the difference between the phone measured with and without the person present, show for GSM900 a very large variation of 7 dB to 20 dB. 20 dB is equivalent to 100 times less power received at the base station.

If a radio performance requirement of mobile phones was introduced to ensure a variation of e.g. less than 6 dB then more than 2/3 of the phones will pass for any given band, system and position even for voice service. With a low variation among the phones, the demand for a given network coverage could be fulfilled with significantly lower cost.

For data services, the variation in TIS among the phones is less than for the mobile phones, from 7 dB spread to a max spread of 10 dB over the systems and bands. For 4/5 of the phones in any given band and system, the variation is less than 6 dB.

The change in data-rate for a TIS difference depends on the radio channel condition, absolute signal level, received type, antenna system, network settings and conditions etc. But as an example, for a simple case with low signal strength a 7 dB reduction in TIS results in a reduction in the data-rate from e.g. 1 Mbit/sec to 0,2 Mbit/sec [Rup16, Mer11]. This means it will take 5 times longer to download from the network with a low performing phone than a good performing phone and for many data services 1 Mbit/sec is often sufficient whereas 0,2 Mbit/sec is not.

The body-loss for data service for the LTE2600, is only some 2- 5 dB.

The performance of the four tablets measured in free space differs with 1dB to 2,6 dB. One of the tablets measured in the two-hand position has a loss of approximately 5 dB, while the other three tablets had 1dB or less due to the phantom hands holding the tablet. The higher loss for the Sony Experia Z4 tablet may be explained by that the phantom hands were placed over the antennas with the orientation used during the measurements. The tablets can be used in both portrait and landscape and also oriented up or down as the display detects orientation and flip but some tablets may have an intended orientation indicated by the microphone, logo camera etc. As the tablets are very large compared to the area covered by the hands a significant lower loss can be expected compared to the mobile phones.

Conclusions

A very large variation for voice communication performance was found among the tested mobile phones. Up to 15 dB variation was seen between all phones measured at the same side of the head at the most important frequency band 900 MHz. This is even a larger variation that seen in the previous investigations [Ped12, Ped13].

For many phones the voice communication performance depends strongly on which side of the head the phone is used. Up to 12 dB variation between left and right side of the head was seen for the pone with the highest variation.

Variation among phones for data service is less than for voice service but still significant. A variation of some 7 to 10 dB across frequency bands and systems was seen. The lower variation for data service is likely explained by the fact that only the phantom hand is present for typical use and not the phantom head.

Variations among tablets are small typically only 1 dB and worse case 2,5 dB. The tablet performance is generally better than the mobile phones. The loss when the tablet is hand held is also small, typical only 1 dB with a worse case of about 5 dB.

Main conclusion is that the variation in communication performance among the tested mobile phones is very large which will result in very large variation in perceived coverage. Earlier it has been demonstrated that a 7 dB difference in phone performance can result in a largely reduced coverage [Erst12]. It is recommended that a standard is set for the minimum accepted communication performance. Such a standard could be set by e.g. ETSI. Alternatively the test results for each phone should be public available to guide the consumers when buying mobile phones.

For the measurements on data services, the terminal was hand held but without the presence of a phantom head. The variation in performance is still significant, but not as large as for the voice measurements were also a phantom head was used.
For consumers to relate the degradation in TIS values into a consumer related value it is recommended to incorporate the selection of a TIS reduction in the coverage tools operators provide for the consumers already. As an example, it should be possible for the consumer to choose the TIS value (in dBm) of the phone of interest directly in the interactive coverage maps provided by the operators. This way it is transparent to the consumers in a similar way as the coverage for voice coverage.

References

[Ped12]	*Limit Values for Downlink Mobile Telephony in Denmark*. Pedersen, Gert Frølund http://vbn.aau.dk/files/75767053/Limit_values_for_Downlink_Mobile_Telephony_in_Denmark.pdf
[Ped13]	*Mobile Phone Antenna Performance 2013*. Pedersen, Gert Frølund http://vbn.aau.dk/files/168617784/MobilephoneTest2013Ver2_2_4_.pdf
[CTI15]	Test Plan for Wireless Device Over-the-Air Performance, revision 3.4.2 September 2015 http://www.ctia.org/docs/default-source/default-document-library/ctia_ota_test_plan_rev_3_4_2.pdf?sfvrsn=2
[Pel09]	*A Grip Study for Talk and Data Modes in Mobile Phones.* Pelosi, Mauro; Franek, Ondrej; Knudsen, Mikael; Christensen, Morten; Pedersen, Gert Frølund. In: IEEE Transactions on Antennas and Propagation, Vol. 57, No. 4, 2009, p. 856-865.
[Jak74]	*Microwave mobile Communications* edited by William C. Jakes, IEEE Press, ISBN 0780310691
[Erst12]	*Mobilkortlægning 2012, ISSN 2245-729, http://www.ens.dk/sites/ens.dk/files/energistyrelsen/Publikationer/mobkort-2012-rapport1.pdf*
[Rup16]	M. Rupp, S. Schwarz, M. Taranetz (ed.) "The Vienna LTE-Advanced Simulators"; Springer-Verlag, Singapore, 2016, ISBN: 978-981-10-0616-6; 383 pages.
[Meh11]	C. Mehlführer, J. Colom Ikuno, M. Simko, S. Schwarz, M. Wrulich, M. Rupp, "The Vienna LTE Simulators - Enabling Reproducibility in Wireless Communications Research"; EURASIP Journal on Advances in Signal Processing, Vol. 2011 (2011), 1 - 13.

Appendix I: Measurement equipment used

Equipment	Serial number	Uncertainty on TIS
TIS test system Starlab-15 (BC)	0125B-0009	< ± 1,8 dB
TRP test system Starlab-15 (BC)	0125B-0009	< ± 1,5 dB
Communication tester R&S CMW 500	1201.000K50- 106102-W1	
Communication tester R&S Cmu 200	110106	
Phantom hand incl. spacer + test cube Speag SHOV 2 RP Right PDA Hand	25382	
Phantom hand incl. spacer + test cube Speag SHOV 2 RB Brick Right Hand	5367	
Phantom hand incl. spacer + test cube Speag SHOV 2 LP Left PDA Hand	20258	
Phantom hand incl. spacer + test cube Speag SHOV 2 LB Brick Left Hand	1229	
Phantom head V 4.5 BS Speag SAM	3481	
Phantom hand incl. spacer + test cube Speag SHOV 2 RD Data Hand Right	35205	
Phantom hand incl. spacer + test cube Speag SHOV 2 RW Right Ultra Wide Hand	2328	
Phantom hand incl. spacer + test cube Speag SHOV 2 LW Left Ultra Wide Hand	1312	

The test equipment consists of a ring with test probes and some instruments to establish a phone call and receive the measured data from the phone under test. The antenna ring with the probes is from Satimo and called the Starlab, the tester for communication with the phone is the CMU200 for UMTS and GSM and the CMW500 for LTE. Further a head-phantom is used; it is the so called SAM head as specified by the CTIA [CTIA15]. And the last part is the hands where 3 different hands are used to fit the different types of phones tested as specified by CTIA [CTIA15] for each side of the head.Further two hands for tablet tests are used.